CLAIMS

What is claimed is:

1. A magnetic field gradiometer detector for detecting a material of interest positioned in a detecting region outside the detector, comprising:

a transmitter for generating an output signal at a selected frequency;

a receiver for detecting the signal;

a probe;

a switch coupling said receiver and said transmitter with said probe for alternately connecting and disconnecting said receiver and said transmitter to said probe, thereby switching said detector between a transmitting mode and a receiving mode; and

wherein said probe comprises a gradiometer coil array including a first surface coil and a second surface coil wound in an opposite sense, said probe has a first side and an opposite second side, and wherein said first and second surface coils are configured asymmetrically such that the probe projects a magnetic field in the outside detecting region adjacent to said first side and is self-shielded on said second side of the probe to thereby detect the material of interest while shielding the detector from outside RF sources.

2. A detector as in claim 1, wherein the transmitting and/or receiving coil within the probe has been optimized based on a parameter that characterizes the effectiveness of the coil as a transmitter and/or a receiver.

3. A detector as in claim 2, wherein said parameter is selected from the group consisting of the filling factor (*f*), which is the ratio of magnetic energy which can be produced in all space to the magnetic energy within a specified inspection region, and the excitation efficiency (*g*), which is the magnetic field energy which can be produced within the inspection region per unit power dissipated in the coil.

4. A detector as in claim 1, wherein said first and second coils are spaced apart and substantially coaxial and electrically connected for transmitting and/or receiving a common but opposite current flow, and wherein said first coil has a different number of spaced-apart coil windings than said second coil, thereby shielding the second side of the probe while projecting the magnetic field in the outside detecting region adjacent to the first side of the probe.

5. A detector as in claim 4, wherein the spacing between the windings of each of said first and second coils is proportional to the inverse of a current density, $K_c^{(i)}(r)$, determined according to the equation:

$$K_c^{(i)}(r) \propto \int_0^\infty \alpha A_i(\alpha) J_1(\alpha r) d\alpha$$

where r is the radial distance from the center of the coil, $i = 1$ or 2 corresponds to said first and second coils, respectively, J_1 is a Bessel function, where $A_1(\alpha) = -A_2(\alpha)e^{\alpha d}$ and d is the spacing between the two coils.

6. A detector as in claim 5 wherein $A_1(\alpha)$ is determined by finding an eigenfunction of a specified function $\tilde{G}(\alpha, \alpha')$ which has the largest eigenvalue.

7. A detector as in claim 6 wherein

$$\tilde{G}(\alpha',\alpha) = G(\alpha',\alpha)\frac{1-e^{-2\alpha d}}{\sqrt{1-(2\alpha d+1)e^{-2\alpha d}}}\frac{1-e^{-2\alpha' d}}{\sqrt{1-(2\alpha' d+1)e^{-2\alpha' d}}}$$ and

$$G(\alpha',\alpha) = a\frac{\alpha\alpha'}{\alpha^2-\alpha'^2}\left(e^{-(\alpha+\alpha')b} - e^{-(\alpha+\alpha')c}\right)\left(J_1(\alpha a)J_0(\alpha' a) - J_0(\alpha a)J_1(\alpha' a)\right)$$

where J_1 and J_0 are Bessel functions, a, b, and c are dimensions characteristic of a desired inspection region and $A_1(\alpha)$ is related to the eigenfunction with the largest eigenvalue, $\tilde{A}(\alpha)$, by

$$\tilde{A}(\alpha) = A_1(\alpha)\sqrt{1-(2\alpha d+1)e^{-2\alpha d}} \quad .$$

8. A detector as in claim 4, wherein said first and second coils are about 30 cm. in diameter.

9. A detector as in claim 1, wherein the coil array has a quality factor greater than about 150.

10. A detector as in claim 1, further comprising tuning elements.

11. An NQR magnetic radiofrequency gradiometer coil array, comprising:

a first surface coil and a second surface coil wound in an opposite sense, and wherein said first and second surface coils are configured asymmetrically such that the coil array projects a magnetic field in a detecting region outside a first side and is self-shielded on a second, opposing side of the coil array to thereby detect a material of interest while shielding the coil array from outside RF sources.

12. A coil array as in claim 11, wherein the transmitting and/or receiving coil within the probe has been optimized based on a parameter that characterizes the coil efficiency.

13. A coil array as in claim 12, wherein said parameter is selected from the group consisting of the filling factor (f), which is the ratio of magnetic energy which can be produced in all space to the magnetic energy within

a specified inspection region, and the excitation efficiency (g), which is the magnetic field energy which can be produced within the inspection region per unit power dissipated in the coil.

14. A coil array as in claim 11, wherein said first and second coils are spaced apart and substantially coaxial and electrically connected for transmitting and/or receiving a common but opposite current flow, and wherein said first coil has a different number of spaced-apart coil windings than said second coil, thereby shielding the second side of the probe while projecting the magnetic field in the outside detecting region adjacent to the first side of the probe.

15. A coil array as in claim 14, wherein the spacing between the windings of each of said first and second coils is proportional to the inverse of a current density determined according to the equation:

$$K_c^{(i)}(r) \propto \int_0^{\infty} \alpha A_i(\alpha) J_1(\alpha r) d\alpha$$

where r is the radial distance from the center of the coil, $i = 1$ or 2 corresponds to said first and second coils, respectively, J_1 is a Bessel function, where $A_1(\alpha) = - A_2(\alpha) e^{\alpha d}$ and d is the spacing between the two coils.

16. A coil array as in claim 15 wherein $A_1(\alpha)$ is determined by finding an eigenfunction of a specified function $\tilde{G}(\alpha, \alpha')$ which has the largest eigenvalue.

17. A coil array as in claim 16 wherein

$$\tilde{G}(\alpha', \alpha) = G(\alpha', \alpha) \frac{1 - e^{-2\alpha d}}{\sqrt{1 - (2\alpha d + 1) e^{-2\alpha d}}} \frac{1 - e^{-2\alpha' d}}{\sqrt{1 - (2\alpha' d + 1) e^{-2\alpha' d}}} \quad \text{and}$$

$$G(\alpha', \alpha) = a \frac{\alpha \alpha'}{\alpha^2 - \alpha'^2} \left(e^{-(\alpha + \alpha')b} - e^{-(\alpha + \alpha')c} \right) \left(J_1(\alpha a) J_0(\alpha' a) - J_0(\alpha a) J_1(\alpha' a) \right)$$

where J_1 and J_0 are Bessel functions, a, b, and c are dimensions characteristic of a desired inspection region and $A_1(\alpha)$ is related to the eigenfunction with the largest eigenvalue, $\tilde{A}(\alpha)$, by

$$\tilde{A}(\alpha) = A_1(\alpha) \sqrt{1 - (2\alpha d + 1) e^{-2\alpha d}} \quad .$$

18. A coil array as in claim 14, wherein said first and second coils are about 30 cm. in diameter.

19. A coil array as in claim 11, wherein the coil array has a quality factor greater than about 150.

20. A coil array as in claim 11, further comprising:

a transmit/receive mechanism to switch between a first state where the coil is used to receive, and a second state where the coil is used to transmit.

21. A coil array as in claim 11, wherein the coil array is for use in one of the group consisting of Magnetic Resonance Imaging (MRI), Nuclear Magnetic Resonance (NMR), Nuclear Quadrupole Resonance (NQR) and Electron Paramagnetic Resonance (EPR).

22. A coil array as in claim 11, further comprising tuning elements.

23. A method for analyzing a sample by magnetic resonance, comprising the steps of:

(a) generating a train of radio frequency pulses having a predetermined frequency;

(b) transmitting said train of radio frequency pulses to a magnetic gradiometer coil array, wherein said gradiometer array comprises a first surface coil and a second surface coil wound in an opposite sense, and wherein said first and second surface coils are configured asymmetrically such that the coil array projects a magnetic field in a detecting region outside a first side and is self-shielded on a second, opposing side of the coil array;

(c) irradiating said sample in response to said train of radio frequency pulses transmitted to said coil at said step (b);

(d) detecting a signal in response to irradiating the specimen at said step (c); and

(e) receiving said signal detected at said step (d).

24. A method as in claim 22, wherein the transmitting and/or receiving coil array within the probe has been optimized based on a parameter that characterizes the coil efficiency.

25. A method as in claim 24, wherein said parameter is selected from the group consisting of the filling factor (f), which is the ratio of magnetic energy which can be produced in all space to the magnetic energy within a specified inspection region, and the excitation efficiency (g), which is the magnetic field energy which can be produced within the inspection region per unit power dissipated in the coil.

26. A method as in claim 23, wherein said first and second coils are spaced apart and substantially coaxial and electrically connected for transmitting and/or receiving a common but opposite current flow, and wherein said first coil has a different number of spaced-apart coil windings than said second coil, thereby shielding the second side of the probe while projecting the magnetic field in the outside detecting region adjacent to the first side of the probe.

27. A method as in claim 26, wherein the spacing between the windings of each of said first and second coils is proportional to the inverse of a current density, $K_c^{(i)}(r)$, determined according to the equation:

$$K_c^{(i)}(r) \propto \int_0^{\infty} \alpha A_i(\alpha) J_1(\alpha r) d\alpha$$

where r is the radial distance from the center of the coil, $i = 1$ or 2 corresponds to said first and second coils, respectively, J_1 is a Bessel function, where $A_1(\alpha) = -A_2(\alpha)e^{\alpha d}$ and d is the spacing between the two coils.

28. A method as in claim 27 wherein $A_1(\alpha)$ is determined by finding an eigenfunction of a specified function $\tilde{G}(\alpha, \alpha')$ which has the largest eigenvalue.

29. A method as in claim 28 wherein

$$\tilde{G}(\alpha', \alpha) = G(\alpha', \alpha) \frac{1 - e^{-2\alpha d}}{\sqrt{1 - (2\alpha d + 1)e^{-2\alpha d}}} \frac{1 - e^{-2\alpha' d}}{\sqrt{1 - (2\alpha' d + 1)e^{-2\alpha' d}}}$$ and

$$G(\alpha', \alpha) = a \frac{\alpha\alpha'}{\alpha^2 - \alpha'^2} \left(e^{-(\alpha+\alpha')b} - e^{-(\alpha+\alpha')c}\right)\left(J_1(\alpha a) J_0(\alpha' a) - J_0(\alpha a) J_1(\alpha' a)\right)$$

where J_1 and J_0 are Bessel functions, a, b, and c are dimensions characteristic of a desired inspection region and $A_1(\alpha)$ is related to the eigenfunction with the largest eigenvalue, $\tilde{A}(\alpha)$, by

$$\tilde{A}(\alpha) = A_1(\alpha)\sqrt{1 - (2\alpha d + 1)e^{-2\alpha d}} \quad .$$

30. A method as in claim 26, wherein said first and second coils are about 30 cm. in diameter.

31. A method as in claim 23, wherein the coil array has a quality factor greater than about 150.

32. A method as in claim 23, further comprising providing tuning elements for said coil array.